Investigating the Identification, Classification, and Layout Patterns of TOD Corridors from the Perspective of Passenger Flow Equilibrium: A Case Study of Shanghai

LIU Bing, WANG Zhiwei, WANG Geyang, ZHU Junyu, CAO Juanjuan, XU Lei

Abstract: The equilibrium of passenger flow between stations within Transit-Oriented Development (TOD) corridors is pivotal to their operational performance, and the connection between various stations in the corridor assumes a decisive role. With Origin-Destination data of rail transit of Shanghai City, community detection algorithm is applied to identify closely connected station communities, then delineating the spatial range of each TOD corridor. The corridors are divided into radial, orthogonal, and curved types. Profile Equilibrium Index and Directional Equilibrium Index are constructed to measure the equilibrium levels of passenger load distribution, which reveal significant differences among corridors. A two-dimensional categorization of TOD corridors is conducted, forming four types as dual-equilibrium, directional-equilibrium, profile-equilibrium, and dual-disequilibrium. It is found that dual-equilibrium corridors are characterized by polycentric and mixed land use, while dual-disequilibrium ones are characterized by a string of suburban residential areas. 5D principles for TOD corridor as a spatial unit are proposed from the perspective of passenger flow equilibrium. With the method of corridor division and its passenger flow equilibrium evaluation, an integrated technical framework for Corridor-TOD with spatial optimization and Station-TOD synergies can be provided.

Keyword: TOD corridor; passenger flow equilibrium; profile equilibrium index; directional equilibrium index; spatial pattern of corridor-TOD; Shanghai

Chinese Library Classification No.: TU984; Document Code: A

DOI: 10.16361/j.upf.202501014; Article No.: 1000-3363(2025)01-0102-09

Author Biography: LIU Bing, Professor and Doctoral Supervisor, College of Architecture and Urban Planning, Tongji University; Key Laboratory of Spatial Intelligent Planning Technology, Ministry of Natural Resources; Shanghai Key Laboratory of Urban Renewal and Spatial Optimization Technology; and Key Laboratory of Ecology and Energy-Saving Study of Dense Habitat, Ministry of Education (Tongji University). Email: liubing1239@tongji.edu.cn; WANG Zhiwei, Doctoral Candidate, College of Architecture and Urban Planning, Tongji University; Planning Director and Senior Planner, Institute of Urban Transport Planning, Suzhou Planning & Design Research Institute Co., Ltd.; WANG Geyang, Engineer, Shanghai Tongji Urban Planning and Design Institute Co., Ltd.; corresponding author. Email: wgy_8d183f@126.com; ZHU Junyu, Engineer, Shanghai Institute of Urban and Rural Construction and Transportation Development; CAO Juanjuan, Deputy Chief Planner and Senior Engineer, Shanghai Tongji Urban Planning and Design Institute Co., Ltd.; XU Lei, Doctoral Candidate, College of Architecture and Urban Planning, Tongji University; Deputy Chief Engineer and Senior Engineer, Institute of Urban Space and Transport Planning and Design, Shanghai Tongji Urban Planning and Design Institute Co., Ltd.

Funding: General Program of the National Natural Science Foundation of China, “Spatial Patterns and Optimization Strategies of Rail-Transit TOD Corridors from the Perspective of Passenger-Flow Equilibrium: A Case Study of the Shanghai Metropolitan Area” (Grant No. 52178052); 2024 Ministry of Education Industry-University Collaborative Education Project of Shanghai Tongji Urban Planning and Design Institute Co., Ltd., “Case-Based Public-Transport Planning Using Digital Technologies” (Project No. 231100155192902); and 2022 Shanghai Decision-Consulting Research Special Project on New-

Town Planning and Construction, “Strategies for Integrating Green and Low-Carbon Transport Construction with Urban Space in Shanghai New Towns under High-Quality Development” (Project No. 2022-Z-W07-A).

1 Research Background

1.1 The Emergence and Practical Application of the TOD Concept

In 1993, Peter Calthorpe[1], building on the theory of New Urbanism, proposed transit-oriented development (TOD) as “compact development in support of public transport.” The concept responded to the smart-growth movement in North America, prompted a reassessment of rail-corridor development experience in Europe and Asia, and stimulated numerous TOD practices coordinated with public-transport investment. TOD has consequently become a major planning concern over the past three decades. Its principles—pedestrian friendliness, mixed uses, housing diversity, and the creation of public centers—align with sustainability goals such as containing urban sprawl, improving air quality, and promoting social interaction. Cities, regions, and national governments have therefore introduced TOD policies, including manuals or regulations in Denver[2], Austin[3], and Delhi[4]; strategies and guidelines for Central Maryland[5] and the San Francisco Bay Area[6]; Malaysia’s national TOD policy[7]; and project assistance from international organizations such as the Institute for Transportation and Development Policy[8] and the World Bank[9].

The TOD concept was introduced into China around 2000[10]. Early studies emphasized how TOD land-use patterns could support public transport and address motorization-related problems[11]. “Accelerating the establishment of an urban development model oriented toward public transport” was subsequently incorporated into the requirements for the National Transit Metropolis Demonstration Program[12]. As urban rail mileage expanded, greater attention was given to rail-plus-property strategies that use development returns to finance rail construction and operations. In 2016, the National Development and Reform Commission convened a seminar on innovative investment and financing mechanisms for urban rail transit[13], and research on rail-transit value capture increased[14-18]. Local TOD practice has also flourished. Beijing, Tianjin, Shenzhen, Chengdu, Hangzhou, Nanjing, Dongguan, Foshan, Suzhou, and many other cities have prepared TOD strategies or special plans. In more than half of the fifty-plus Chinese cities with operating rail systems, policies have reportedly been adopted to encourage integrated development around rail stations[19].

1.2 Growing Attention to Corridor TOD

As a leading New Urbanist concerned with regional growth, Calthorpe emphasized that TOD is fundamentally “a regional development model of New Urbanism” that integrates public transport and land-use patterns at the regional scale to produce a more compact spatial form[21]. Regional TOD is achieved through coordinated neighborhood-scale station TODs along trunk and feeder routes[1], while the resulting ordered corridor network depends on the public-transport network to coordinate urban structure[22]. Influenced by the “3D” principles[23], early TOD research and practice focused on the neighborhood scale and on how improvements to the station-area built environment could encourage transit use[24-25]. Yet isolated station TODs can become disconnected “islands”[26]. To capture TOD’s network effects, research has shifted toward larger scales[27], and increasing attention has been paid to Corridor TOD (CTOD), which coordinates development among stations along a route. TOD has thus evolved from a neighborhood-scale community-planning tool into a regional urban-restructuring strategy[28].

The early U.S. manual Station Area Planning: How to Make Great Transit-Oriented Places listed the “mixed-use corridor” as one type of TOD station area[29]. The later report Transit Corridors and TOD:

Connecting the Dots distinguished three spatial levels—station, corridor, and region—and further classified corridor TOD into destination, commuter, and district-circulator types[30]. China's Guidelines for Planning and Design of Areas along Urban Rail Transit likewise proposed TOD guidance at the city, line, and station levels[31], and the Ministry of Housing and Urban-Rural Development subsequently established a three-tier evaluation framework on its TOD platform. TOD is now understood as a multi-scalar spatial-development model that combines neighborhood layouts with broad transit strategies and integrates land-use and transport planning to maximize transit-passenger efficiency[32]. Located between the city and station scales, corridor TOD plays an important role in coordinating station TODs into hierarchical networks of different scales, functions, and forms[30].

1.3 The Relative Lag in Corridor-TOD Research

Although the larger network effects of corridor TOD are increasingly recognized[33], planning methods for the corridor scale remain underdeveloped. In the theoretical extension from the "3D" to the "5D" principles, only destination accessibility reflects the significant influence of urban structure and network conditions at the macro scale[24,34]. This indicator measures convenient access from stations to activity centers and other destinations, but it does not constitute a multidimensional framework for planning corridor TOD. Bertolini's node-place model[35] can evaluate the correspondence between station-node and place values across multiple stations in a corridor or region, yet it remains a station-based method. Recent studies have combined the D principles with the node-place model to classify TODs[36-37], but they have not moved beyond the station as the analytical unit and therefore cannot reveal the integrated development characteristics of corridor TOD or their relationship with transit passenger flows. Treating the transit corridor as the spatial unit of TOD research is consequently essential[38-39]. It creates planning opportunities to improve transit through land-use changes along the route and provides a basis for evaluating coordination among station TODs. As one review notes, improving transit operating performance is a principal field of corridor-TOD research[33].

Current shortcomings in corridor-TOD research can be summarized in three respects. First, the spatial boundaries of transit corridors are defined inconsistently. Some studies select an entire transit line[40]; others begin at the corridor's highest-load section and extend 3-5 km in both directions[41]; still others use a travel-shed range of 55-65 minutes or 15-20 miles (24-32 km)[28], or adopt community-detection algorithms[42]. These different definitions reduce comparability. Second, insufficient attention has been paid to passenger-flow distributions and operating conditions. Many studies advocate high-intensity station-area development to increase transit use, while few recognize the adverse effects of very high section loads in dense areas. In Taipei, for example, development intensity above a certain threshold has been found to impair transit operations and public-facility service levels[43]. Third, measurements of corridor land-use-transport relationships remain inadequate, and quantitative indicators of the corridor built environment and passenger-flow characteristics are lacking. Research on corridor layout from the perspective of passenger-flow equilibrium is beginning to emerge. A study of Bogotá found that jobs-housing mixing along a route can flatten passenger peaks and improve section-flow equilibrium[44], and Chinese scholars have examined pendulum commuting and passenger-load balancing in rail systems[45-46]. Nevertheless, theoretical and methodological research on corridor-TOD planning remains limited.

This study therefore develops a corridor-level TOD planning framework from the perspective of passenger-flow equilibrium. Beginning with the definition of corridor sections, it measures equilibrium levels and spatial-layout patterns across different corridors in order to support coordinated development among station TODs and improve transit operating performance.

2 Identification of TOD Corridors Based on Closely Connected Sections

2.1 Method for Identifying TOD Corridors

A TOD corridor is a route section with close internal connections that accommodates the principal transit trips along the line. Drawing on the concept of the travel shed[33], this study defines the specific extent of a TOD corridor according to the spatial distribution of passenger trips within the area served by a transit route. Origin-destination data between Shanghai rail-transit stations are used with a community-detection method to identify communities of closely connected stations, which then provide the basis for corridor delineation. Full-day station-to-station OD data for a weekday in July 2022 were used. Passenger flows at interchange stations were first assigned to stations on specific lines (for example, People's Square Station on Line 1 and People's Square Station on Line 2). A weighted undirected graph G=(V,E) was then constructed from passenger volumes. The vertex set V consists of metro stations associated with specific lines, the edge set E represents passenger-flow connections between station pairs, and the weight of an edge $e(v_1,v_2)$ is the total passenger flow between the two corresponding stations①.

The modularity-based Louvain community-detection algorithm② was selected to divide network nodes into groups with denser internal connections and sparser external connections, thereby identifying TOD "corridor communities." Because communities produced by the Louvain algorithm tend to have similar total internal flow, high-volume lines may be divided into several communities while lower-volume lines remain undivided. A two-stage "overall division followed by subdivision" procedure was therefore used. With the initial resolution parameter set to 2, high-volume lines were first divided into several relatively large communities with similar internal passenger volumes. Community detection was then repeated within each large community to obtain smaller subcommunities. When stations belonging to one community were interspersed discontinuously among stations of another, the interspersed stations were treated as overlapping portions of the communities. This procedure yielded a series of continuous TOD corridors③.

2.2 Results of TOD-Corridor Identification

The method identified 41 TOD corridors across Shanghai, including three branch corridors; most metro lines were divided into two or three corridors (Fig.1). Based on corridor geometry, the results can be grouped into radial, orthogonal, and curved types. The 22 radial corridors have an average length of approximately 25.0 km and an average of 14 sections. The 13 orthogonal corridors and six curved corridors are concentrated in and around the central city; both contain about 12 sections on average and have similar mean lengths of 16.1 km and 15.8 km, respectively—approximately two thirds the length of radial corridors—mainly because their station spacing is smaller.

Radial corridors primarily connect the central city with new towns, suburban settlements, Pudong International Airport, and other peripheral areas. Orthogonal corridors form the dense rail network traversing the central city, especially Puxi. Curved corridors occur mainly along ring lines and route segments with major directional changes and primarily connect Puxi and Pudong. Because central-city rail connections are networked through multiple interchanges and interwoven routes, orthogonal and curved corridors overlap extensively with other corridors. A given segment or station may therefore belong to more than one TOD corridor rather than exhibiting a strict one-to-one relationship, confirming the partial interpenetration observed among corridor communities. See Tab.1.

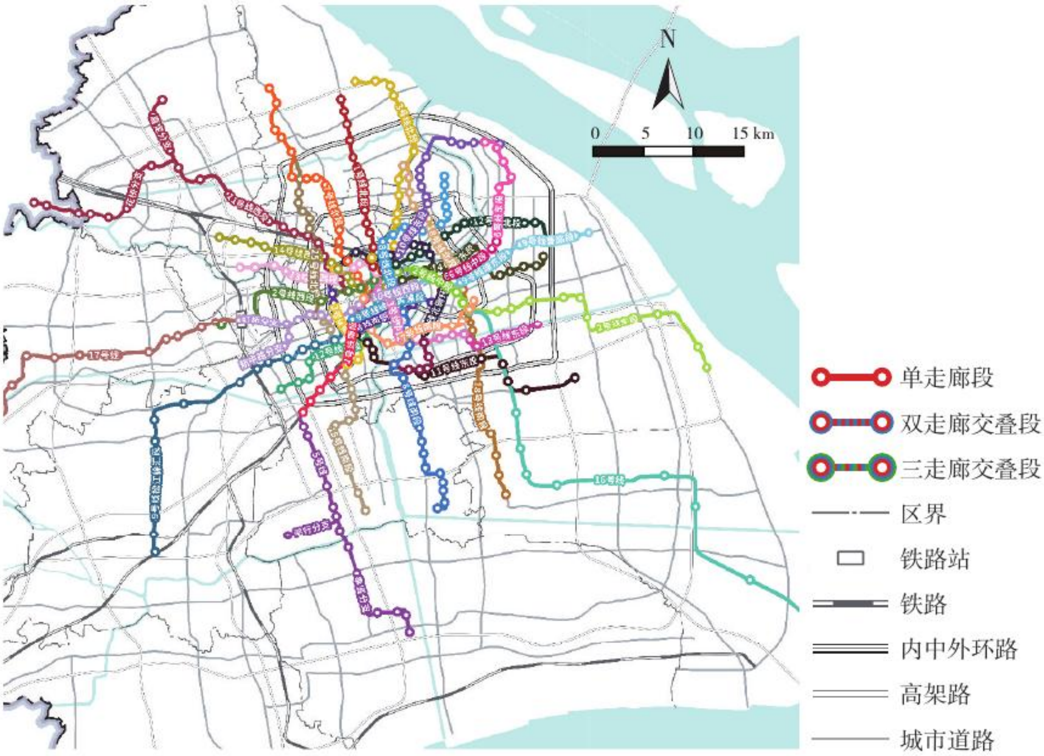


Fig.1 TOD corridors in Shanghai

Tab.1 Identification and typological classification of TOD corridors

走廊形态		构成
放射走廊	北向	1号线北段(富锦路—人民广场)、3号线北段(江杨北路—上海火车站)、7号线北段(美兰湖—静安寺)、10号线东段(基隆路—豫园)、15号线北段(顾村园—红宝石路)
	南向	5号线闵行分支(闵行开发区—莘庄)、5号线奉贤分支(奉贤新城—莘庄)、8号线南段(汇臻路—大世界)、15号线南段(紫竹高新区—姚虹路)、16号线(滴湖—龙阳路)、18号线南段(航头—杨高中路)
	西向	9号线松江徐汇段(松江南站—宜山路)、11号线西段花桥分支(花桥—江苏路)、11号线西段嘉定分支(嘉定北—江苏路)、17号线(东方绿舟—虹桥2号航楼)
	东向	2号线东段(浦东国际机场—上海科技馆)、6号线东段(港城路—北洋泾路)、9号线浦东段(民雷路—小南门)、9号线曹路段(曹路—台儿庄路)、11号线东(迪士尼—交通大学)、13号线东段(张江路—陈春路)
纵横走廊	横向	2号线西段(徐泾东—人民广场)、2号线中段(龙阳路—南京东路)、9号线徐汇黄浦段(星中路—陆家浜路)、10号线西段航中路分支(航中路—老西门)、10线西段虹桥分支(虹桥火车站—老西门)、12号线东段(金海路—天潼路)、13号线西段(金运路—自然博物馆)、14号线西段(封浜—大世界)、14号线东段(桥路—豫园)
	纵向	1号线南段(莘庄——大会址·黄陂南路)、8号线北段(市光路—人民广场)、12号线西段(七莘路—曲阜路)、18号线北段(长江南路—民生路)
弯绕走廊		3号线南段(上海南站—中潭路)、4号线北侧环(蓝村路—曹杨路)、4号线南侧环(金沙江路—塘桥)、6号线西段(云山路—东方体育中心)、6号线中段(巨路—世纪大道)、7号线南段(花木路—常熟路)、13号线中段(北蔡—南京西路)

3 Passenger-Flow Equilibrium in TOD Corridors

The spatial equilibrium of passenger flows in a TOD corridor has two dimensions: equilibrium among sections along the route and equilibrium between the two travel directions. Corresponding indicators are developed below and used to compare the corridors.

3.1 Evaluation of Profile Equilibrium

Drawing on the statistical concept of kurtosis, this study constructs an indicator of equilibrium in the distribution of passenger flows among corridor sections. Equilibrium is highest when passenger volumes are equal across all sections and the distribution is perfectly uniform. The Profile Equilibrium Index (PEI) is therefore defined as the difference between the kurtosis of the observed passenger-flow profile and that of a uniform distribution.

For the inbound or outbound direction④, PEI is calculated as follows:

$$PEI = kurt(X) - 1.8 = E[((X - \mu)/\sigma)^4] - 1.8$$

where PEI is the corridor profile equilibrium index; kurt(X) is the kurtosis of the observed section-flow curve X; 1.8 is the kurtosis of a uniform distribution; E(x) is the expected value of variable x; μ is the mean of distribution X; and σ is its standard deviation.

In the calculation, passenger volume on each section in a given direction is expressed as a share of the corridor's total section passenger volume. These shares form a section-flow profile from which PEI is calculated. A value of 0 indicates the most even distribution. A negative value indicates greater flows at both ends and lower flows in the middle. When the value is positive, a larger value indicates a more uneven distribution concentrated toward one side. A value near 0.6 corresponds to an approximately linear increase along the route; when the value exceeds 1, the curve contains a low-flow "tail," and the long-tail effect becomes more pronounced as the index rises.

The morning-peak PEI values [Fig.2(a)] show that radial corridors have the lowest profile equilibrium. Their mean inbound and outbound kurtosis values are 0.67 and 0.95, substantially above the 0.39 and 0.48 observed for orthogonal corridors and the 0.49 and 0.28 observed for curved corridors. Although most corridors have lower inbound PEI values, long tails remain conspicuous. Because inbound flow is also larger during the morning peak, the implications for rail operation and service cannot be ignored. Among radial corridors linking the central city and new towns, the inbound PEI values of the Fengxian branch of Line 5, the Songjiang-Xuhui section of Line 9, the Huaqiao branch of the western section of Line 11, Line 16, and Line 17 are all close to 1; the western Jiading branch of Line 11 is the exception.

By contrast, corridors with PEI values below 0.3 are concentrated in the central city, including the central sections of Lines 2, 6, 9, and 13 that pass through the Central Activity Zone and the Line 4 loop with multiple interchange opportunities. Several corridors entering the Central Activity Zone from the surrounding central-city area have inbound PEI values between approximately 0.3 and 0.5 and therefore intermediate equilibrium. This pattern—stable flows in the center but sharp differentials toward the periphery—is closely related to the citywide monocentric structure and the polycentric configuration of the central city.

3.2 Evaluation of Directional Equilibrium

Centripetal tidal commuting produces large ratios between inbound and outbound section flows on radial corridors during the morning peak, reaching approximately 4 on some sections. Because this two-way imbalance coefficient has an unbounded range and positive and negative differences can cancel when values are aggregated across corridor sections, it cannot fully represent directional imbalance for the corridor as a whole. The Directional Equilibrium Index (DEI) is therefore constructed from the differences between flows in the two directions. It is calculated as the root mean square of each section's directional flow difference divided by its total bidirectional flow. DEI measures the overall directional imbalance and also reflects the tidal character of corridor travel. Values range from 0 to 1, with larger values indicating greater imbalance. DEI equals 0 when inbound and outbound flows are identical on every section and equals 1 when one direction carries no passengers.

DEI is calculated as follows:

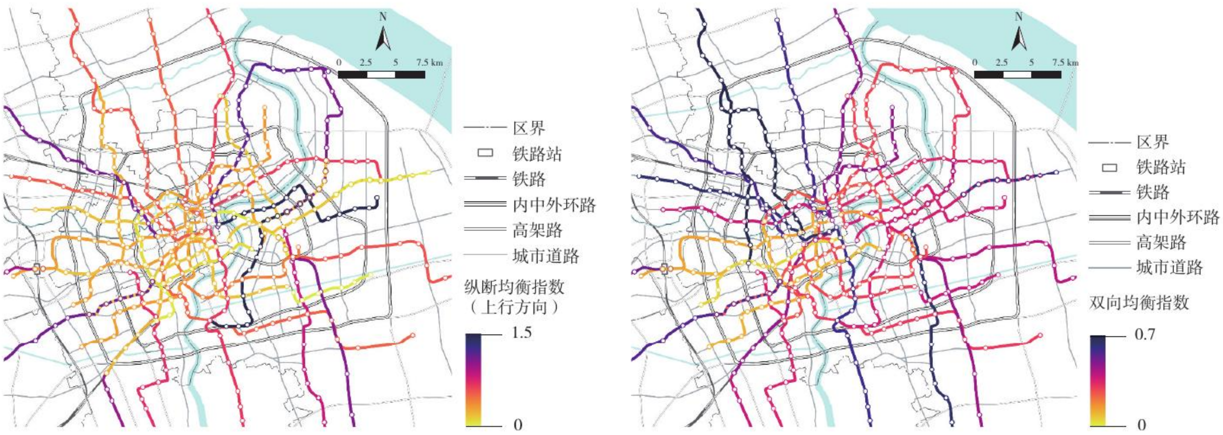
$$DEI = \sqrt{[(1/n)\ \Sigma_i\ ((u_i/f_i) - (d_i/f_i))^2]}$$

where DEI is the directional equilibrium index; u_i and d_i are the inbound and outbound passenger volumes on section i; f_i is the total bidirectional passenger volume on section i, equal to u_i+d_i; and n is the number of sections.

Morning-peak DEI values are mainly between 0.1 and 0.7 [Fig.2(b)]. Values above 0.7 indicate extreme imbalance, corresponding to a directional flow ratio of approximately 6:1. At DEI=0.5, the imbalance remains pronounced and the ratio is about 3:1. At DEI=0.2, directional equilibrium is relatively good and the ratio is about 3:2.

Overall, radial corridors exhibit the most serious directional imbalance [Fig.2(b)]. Corridors lined continuously by residential land—such as the northern sections of Lines 7 and 15 and the southern section of Line 18—show pronounced tidal flows from their outermost sections. Several corridors between the central city and new towns also have DEI values above 0.55, including the western section of Line 9 between the central city and Songjiang New Town, the western section of Line 11 between the central city and Jiading New Town, and Line 17 between the central city and Qingpu New Town. Their values are not the highest, however, because each includes a tail in which flows in both directions are low.

Corridors within the central city have more balanced directional flows, particularly in Puxi. Typical examples include the western and central sections of Line 2, the Xuhui-Huangpu section of Line 9, the western section of Line 10, the southern section of Line 12, and the southwestern half of the Line 4 loop. Together these corridors form a pattern of three east-west axes, one north-south axis, and half a ring. Their DEI values are around 0.2, and spatially they pass through the Central Activity Zone and connect multiple public centers.



（a）上行方向纵断均衡指数 （b）双向均衡指数

Fig.2 TOD corridors based on passenger flow equilibrium in Shanghai

3.3 Two-Dimensional Analysis of Passenger-Flow Equilibrium

To analyze profile and directional equilibrium together, the percentile ranks of each corridor's PEI and DEI among all corridors were calculated. A two-dimensional classification diagram was then constructed in which each corridor is represented by a circle centered on its two percentile ranks; circle size reflects the corridor's mean section passenger volume during the morning peak (Fig.3).

Using the median percentile of each indicator as the dividing line, the corridors fall into four quadrants. Clockwise from the upper right, these are dual-disequilibrium (directionally imbalanced with a long tail), profile-equilibrium only (directionally imbalanced without a long tail), dual-equilibrium (directionally balanced without a long tail), and directional-equilibrium only (directionally balanced with a long tail). Thirteen corridors are dual-equilibrium and fourteen are dual-disequilibrium;

together they account for 66% of all corridors, suggesting a degree of association between profile and directional equilibrium.

The four types also have distinctive spatial distributions. Dual-equilibrium corridors are concentrated west of the Huangpu River and south of Suzhou Creek, an area closely overlapping Shanghai's Central Activity Zone (CAZ), and are generally lined by high-density mixed-use districts. Most directional-equilibrium-only corridors are east of the Huangpu River. Their poor profile equilibrium reflects the rapid decline in development intensity with increasing distance from Pudong's riverside CAZ. Dual-disequilibrium corridors are primarily radial routes extending from the CAZ into the outer suburbs. Their termini are usually in Shanghai's new towns, such as Songjiang and Fengxian, or in areas with similar characteristics, such as Pujiang Town and Wusong. Continuous residential districts lie between these termini and the central city; sections near the outer end often carry little flow and form a pronounced long tail, while passenger volumes rise rapidly at stations serving large residential areas and show strong tidal directionality. Profile-equilibrium-only corridors are shorter radial corridors extending outward from the CAZ. They lack a low-flow tail and thus perform relatively well on PEI, but still exhibit marked tidal flows, as in the northern sections of Lines 8 and 15.

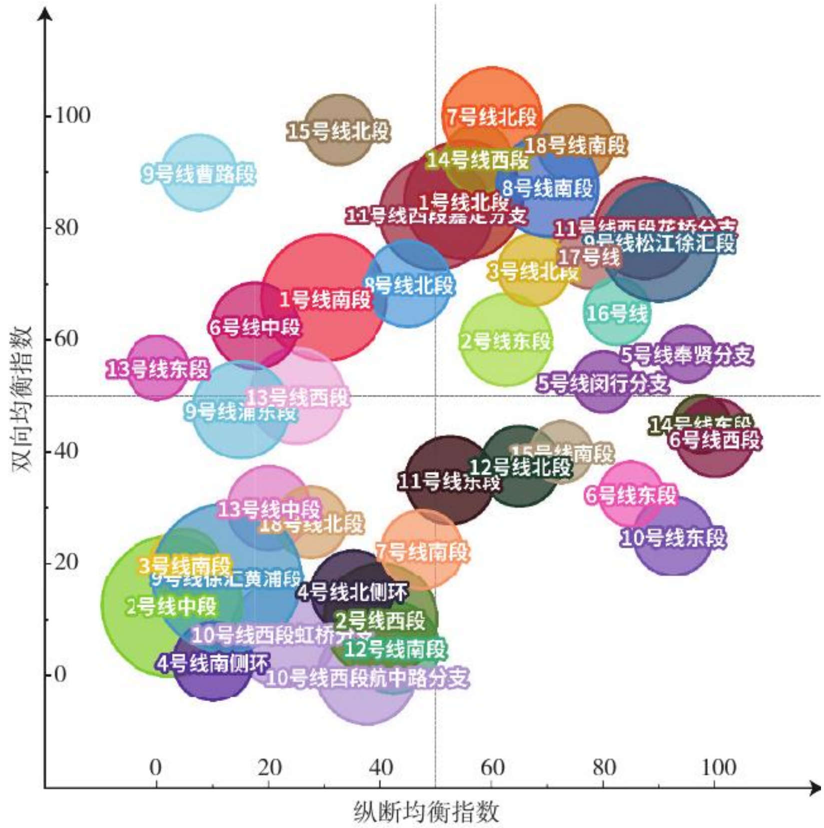


Fig.3 Percentile rank of profile and directional equilibrium indices for corridors

4 Spatial Patterns of TOD Corridors from the Perspective of Passenger-Flow Equilibrium

4.1 Distribution of Station Types along TOD Corridors

The land-use pattern of a TOD corridor is reflected in the functions of its station areas. Stations were classified according to similarities in the shapes of their hourly passenger-flow curves on weekdays and non-workdays. Six types were identified: integrated activity center, office-dominant center, office-led mixed use, diversified mixed use, residential-dominant, and residential-dependent. Across these six categories, the share of office functions declines progressively while the share of residential functions rises. Integrated activity centers and office-dominant centers are concentrated in the CAZ; office-led and diversified mixed-use stations are mainly within the central city; and residential-dominant and residential-dependent stations are located primarily outside the central city along radial corridors.

Dual-disequilibrium corridors are predominantly radial. They connect the residential functions of new towns and other outer-suburban areas with office, commercial, and service functions in the central city and therefore constitute long-distance commuter corridors characterized by jobs-housing separation. Dual-equilibrium corridors, by contrast, are mainly orthogonal routes linking the CAZ and curved sections of ring lines. They connect multiple centers, carry large passenger volumes, and function as destination corridors. The other two categories also exhibit distinct land-use patterns. Corridors with directional equilibrium but poor profile equilibrium typically terminate at mixed-use stations dominated by nonresidential functions. Better jobs-housing balance generates some counter-peak flow, but low peripheral development intensity creates large differences between peripheral and central section volumes. Corridors with profile equilibrium but directional imbalance typically terminate at residential-dependent stations close to the central city. Their surroundings contain abundant housing and section flows are generally saturated, but limited nonresidential uses produce pronounced jobs-housing separation.

4.2 Analysis of Typical Corridors

The Songjiang-Xuhui section of Line 9 is a high-volume dual-disequilibrium corridor. Its station types and section-flow distribution [Fig.4(a)] show a continuous sequence of residential stations in Songjiang, including the residential-dependent stations at Sheshan and Sijing, completely separated from a continuous group of office-oriented stations around Caohejing Activity Center. This spatial separation produces severe passenger-flow imbalance. The directional comparison [Fig.4(b)] shows inbound section flows rising sharply from Sheshan and declining only around Caohejing, while outbound flows fall to a very low level immediately after Caohejing. Consequently, inbound passenger loads are much higher than outbound loads between Songjiang South Railway Station and Xingzhong Road, producing directional imbalance. In the inbound direction, overall flow within Songjiang New Town is low, whereas more than 5,000 passengers enter per hour at Sheshan, Dongjing, and Jiuting. This creates a pronounced long tail in the Songjiang New Town section. In the outbound direction, alighting is concentrated at the Caohejing employment center, causing section flows below Hechuan Road to fall sharply and producing another long tail.

The Hongqiao branch of the western section of Line 10 is a typical dual-equilibrium corridor. Residential stations are few, and most stations are integrated centers, office-dominant centers, or diversified mixed-use areas [Fig.4(c)]. In the inbound direction, boarding and alighting volumes are broadly similar at most stations, except for concentrated alighting at South Shaanxi Road and Songyuan Road, resulting in a relatively even section-flow profile. The corridor's outer terminus is Hongqiao Hub, which generates high boarding volumes at the beginning of the inbound direction and substantial alighting volumes at the end of the outbound direction. This structure improves directional equilibrium, and neither direction contains a low-flow long tail [Fig.4(d)].

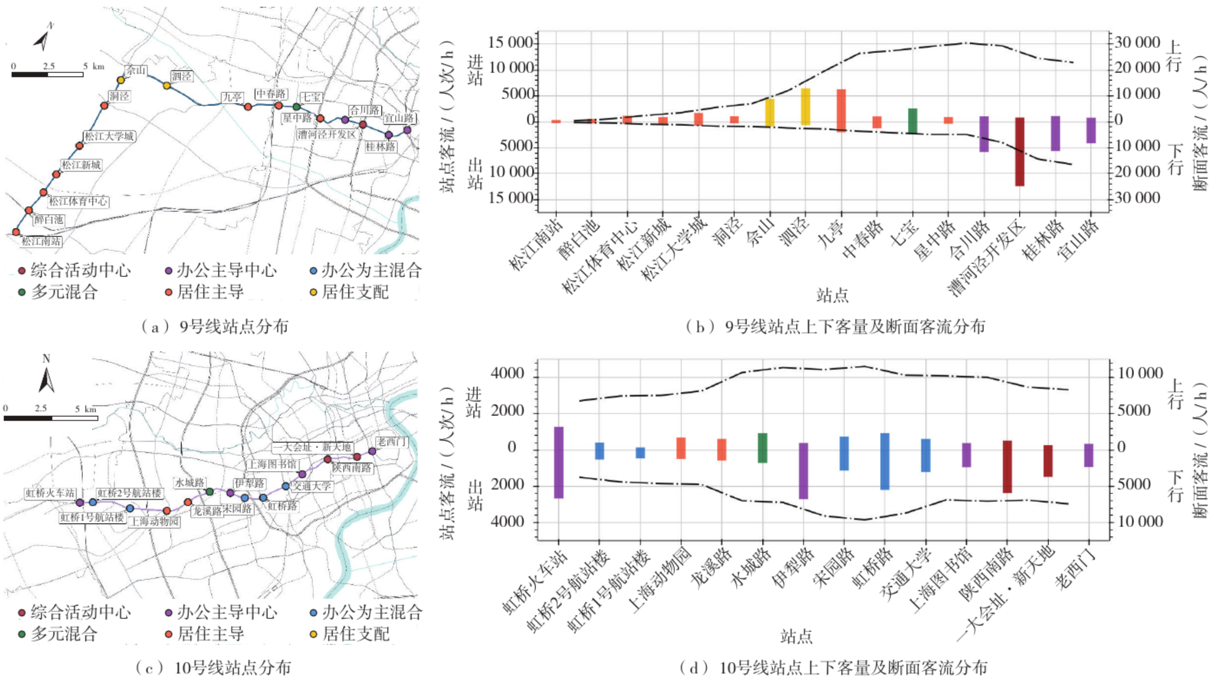


Fig.4 Station boarding-and-alighting volumes and passenger flow profile along Songjiang-Xuhui section of Line 9 and Hongqiao branch of the west section of Line 10

5 Conclusions and Implications

5.1 Main Conclusions

Overall, this study addresses a gap in knowledge about TOD corridors from the perspective of passenger-flow equilibrium. Its findings can support integrated spatial control and optimization at the corridor scale and improve the performance of comprehensive TOD development.

First, the passenger-flow-based method clearly defines the sections constituting a TOD corridor and provides a basis for delineating corridor-level spatial planning units. Community detection applied to station-to-station OD data from Shanghai's rail-transit system identified the TOD corridors. Radial corridors are generally 25-30 km long with mean station spacing of 1.83 km, while corridors in and around the central city are 16-20 km long with mean station spacing of 1.30 km. The ratios between the two groups in both length and station spacing are close to 3:2, reflecting differences in the scales of activity in the areas they serve. The number of stations in each TOD corridor is also close to the number actually traversed in an average trip—approximately twelve—indicating that community detection is suitable for corridor identification. The resulting corridor extents correspond to the spatial characteristics of transit trips and enhance comparability among corridor studies.

Second, profile and directional indicators provide a comprehensive assessment of TOD-corridor operating and service performance and reveal spatial patterns of passenger-flow equilibrium. PEI and DEI differ significantly among corridor types, with radial corridors scoring substantially higher—and therefore performing less evenly—than the other two types (Tab.2). In the two-dimensional classification, dual-disequilibrium corridors are mainly radial routes linking the central city with peripheral areas, whereas typical dual-equilibrium corridors are chiefly orthogonal and curved corridors.

Third, passenger-flow equilibrium is closely related to land-use patterns along the corridor. Destination corridors exhibit relatively balanced flows, whereas commuter corridors show stronger tidal and long-tail effects. Destination corridors spatially overlap the Central Activity Zone, contain diverse station types, and display polycentric, mixed land use. Major activity attractors at both ends help achieve dual-equilibrium in both profile and direction. Radial commuter corridors are characterized by a chain of residential uses in the periphery and office-dominant employment in the central city. This jobs-housing separation substantially reduces operating efficiency and service quality.

Tab.2 Comparison of profile and directional passenger flow equilibrium levels in TOD corridors

走廊类型	总数 / 个	上行方向纵断均衡指数		下行方向纵断均衡指数		双向均衡指数		走廊长度 / km		断面数 / 个		
		均值	标准差	均值	标准差	均值	标准差	均值	标准差	均值	标准差	合计
放射	22	0.67	0.42	0.95	0.90	0.52	0.12	24.99	11.65	13.64	3.87	300
横纵	13	0.39	0.45	0.48	0.45	0.35	0.15	16.14	3.33	12.23	2.59	159
弯绕	6	0.49	0.73	0.28	0.36	0.32	0.08	15.84	1.81	12.50	1.87	75

5.2 Planning Implications

The method for identifying TOD corridors and analyzing their spatial patterns is important for extending multi-scalar TOD theory and guiding corridor planning more scientifically. The proposed station-connectivity-based corridor delineation and passenger-flow equilibrium assessment together provide an integrated technical framework for corridor-level TOD planning and coordination among station TODs.

First, the TOD corridor is a key vehicle for integrating transit operation with station-area development and for implementing transit-oriented development goals. Improving operations and service quality is essential to increasing the attractiveness of transit. Maximizing passenger-transport efficiency requires integrated land-use and transport planning at the regional scale, consistent with TOD's original regional perspective: TOD is a transit-oriented regional development model jointly supported by station TODs linked through the transit network. Station-scale TOD alone cannot adequately respond to the operational requirements of entire transit lines. It often overlooks how development affects operations differently under conditions of passenger-flow saturation or insufficiency and ignores conflicts between high section loads and transit capacity. Integrating isolated station TODs along a corridor can improve the equilibrium of section-flow distributions and connect land development more effectively with the transit-strategy objective of increasing ridership.

Second, planning principles and control strategies should be formulated for the TOD corridor as a unit in order to optimize spatial-layout patterns. Corridors between the central city and peripheral areas should be distinguished from corridors within the central city according to the spatial distribution of transit trips. Compared with station TOD, corridor TOD requires planning and design principles at the regional scale. Based on Shanghai's experience, this study proposes five corridor-level D principles from the perspective of passenger-flow equilibrium: diversity, extending beyond mixed use within individual station areas to intersperse stations with different functional types along the corridor, especially center-type stations; destination accessibility, distributing commercial, office, leisure, and other specialized activity centers along the corridor to enhance the attraction of multiple station areas and balance passenger entries and exits; depolarization, strengthening the functions of new towns and other major nodes and increasing the level of peripheral public centers to reduce the one-way polarization of radial corridors; distance to workplace, arranging employment and residential uses in sections at both ends of the corridor to improve jobs-housing balance and, in particular, avoiding long sequences of single-function residential stations in the periphery; and density leverage, calibrating development intensity to passenger volumes and equilibrium in different corridor sections, appropriately increasing nonresidential intensity in peripheral areas while controlling the functional mix and intensity around high-load sections so that development matches transit capacity.

Third, multi-scenario simulation should be strengthened for TOD-corridor layouts and policies, with higher passenger-flow equilibrium as the objective. Equilibrium improves operating efficiency and can also support the core TOD objective of increasing transit use by reducing onboard crowding and improving comfort. It results from the interaction of land use and transport along the corridor and across the broader region and is affected by alternative spatial layouts and policies; even different sections of the same line may exhibit different equilibrium levels. More scientific corridor planning therefore requires simulation of passenger-flow equilibrium under multiple planning scenarios. Comparing and selecting spatial patterns and strategies for coordinated station TODs can provide quantitative support for functional agglomeration and for realizing corridor-scale spatial effects.

Acknowledgments

The authors thank Senior Engineer ZHANG Hanshuang for valuable guidance during the preparation of this article and MIAO Sijing and LU Ming for their substantial assistance with the literature review.

Notes

① For a graph G with V vertices, when the number of edges E approaches V^2, G is considered a dense graph; conversely, when E approaches V, G is considered a sparse graph. Because passenger flows exist between almost every pair of rail-transit stations, nearly every station pair is connected by an edge, and the graph constructed from interstation passenger-flow relationships is dense. Modularity is calculated from edge weights, namely passenger volumes. In a weighted dense graph, community-detection algorithms tend to produce communities with similar sums of internal edge weights; in this case, total passenger volumes within the communities are therefore similar.

② The Louvain community-detection method is a heuristic algorithm based on modularity maximization. Higher modularity indicates denser connections within communities and sparser connections between communities.

③ Examination of the community-detection results showed that some discontinuous communities could not be directly defined as TOD corridors. Additional processing was therefore required to obtain continuous transport corridors. For a station s assigned to community a on a non-loop rail line, if stations s′ and s″ assigned to community b occur in both directions along that line, station s is considered to belong simultaneously to TOD corridors A and B. Corridors defined by this rule are continuous, although a station may belong to multiple corridors. For example, Beiyangjing Road Station on Line 6 belongs simultaneously to the eastern, central, and western sections of Line 6.

④ Of the two corridor endpoints, the endpoint farther from Shanghai’s city center is defined as origin s_0, while the endpoint closer to the center is destination s_1. The city center is the origin of the Shanghai 2000 coordinate system, physically corresponding to the central flagpole on the roof of the Park Hotel on Nanjing West Road, north of People’s Park. Travel from s_0 toward s_1 is defined as inbound and the reverse as outbound. Some Shanghai metro lines, such as Line 11, have branches located away from the city center. In such cases, the corridor has two origins, s_{01} and s_{02}, and the two paths from these origins to destination s_1 are treated as branches of the same TOD corridor. Passenger-flow equilibrium indicators are calculated separately for each branch.

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Revised: November 2024